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Physics Student Practice 2019

Computational simulation of tunneling characteristics of superconducting nanostructures

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Outline

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Aim and Objectives

Aim: To investigate plasma wave in stacked Josephson Junction (JJ) by using computer simulation.

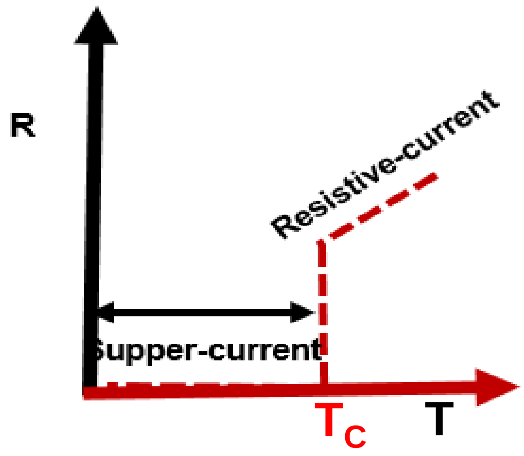
Objectives:

To understand the difference in phase dynamics between the single JJ and CCJJ.

INTRODUCTION

Superconductivity

- Observation of phenomenon of superconductivity
- Two basic properties:
  - No resistance to the passage of electrical current
  - Sufficiently weak, external magnetic field will not penetrate



W. Buckel and R. Kleiner, Superconductivity: fundamentals and applications. (Wisely-VCH, Verlag GmbH &Co. Kga A, 2004)

Brief Background

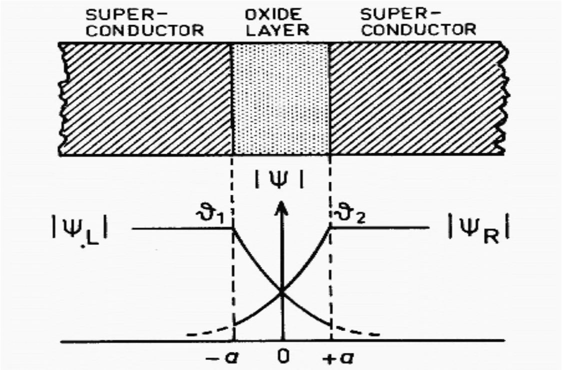
- Josephson Effect was predicted by Brian D Josephson in 1962
- Theoretically, Josephson considered SIS (superconductor-insulator-superconductor) junctions.
- Discovered probability of Cooper pair tunnelling
- Macroscopic wave function describes ensemble of superconducting electrons that is tunnelling through the barrier.

Josephson Junction

Current in junction (J) is then equal to:

$$J = J_c \sin(\phi_1 - \phi_2)$$

Electrical current flows between two SC materials - even when they are separated by a non-SC or insulator. Electrons "tunnel" through this non-SC region, and SC current flows.



$$V(t) = \frac{\hbar}{2e}\frac{d(\phi_1 - \phi_2)}{dt}$$

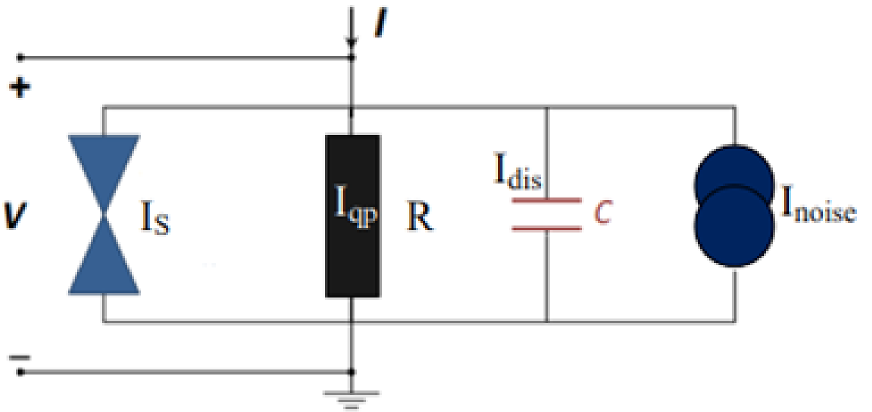
Phase difference=$(\phi_1 - \phi_2)$

Model RCSJ

Resistive and Capacitive Shunted Junction

$$J = J_J + J_{qp} + J_{disp}$$

$$J = J_C Sin\phi + \frac{V}{R} + C\frac{dV}{dt}$$



$$\frac{d\phi}{dt} = V$$

$$\frac{dV}{dt} = I - sin\phi - \beta\frac{d\phi_i}{dt}$$

- $t \rightarrow t/\omega_c$ & $\omega_c = 2\quad I_cR/\quad_0$
- $V = v/(I_cR)$ & $I = i/I_c$
- $\Omega_J = \omega_J/\omega_c$ & $\omega_J = 2e\,v/\hbar$
- & $\Omega_J = V$

$$\beta = \frac{1}{R}\sqrt{\frac{\eta}{2eI_C C}}$$

Yu. M. Shukrinov and M.A Gaafar
Phys. Rev. B 84, 094514(2011).

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Methodology

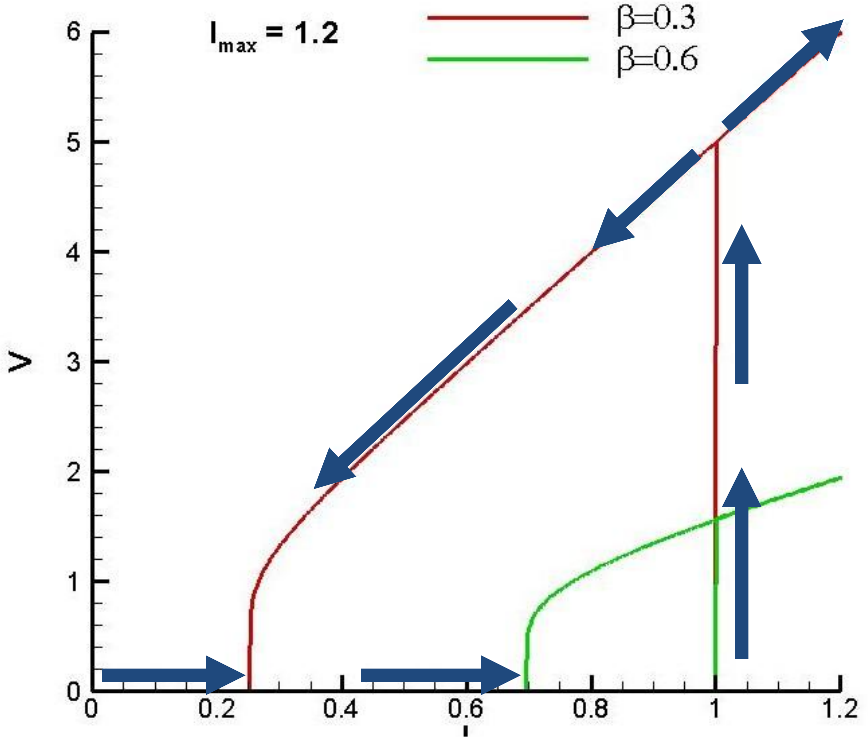
- Numerical simulation using C++ software
  - Understand physics behind Josephson Junction
  - Simulate time averaging from Tmin to Tmax of the V(t) to calculate one point of I(V) curve

- Runge-Kutta method of 4^{th} order to solve differential equations of systems:
  - Simulate dynamics of the phases
  - Obtain time dependences of the phase and voltage at a fixed value of current (I)

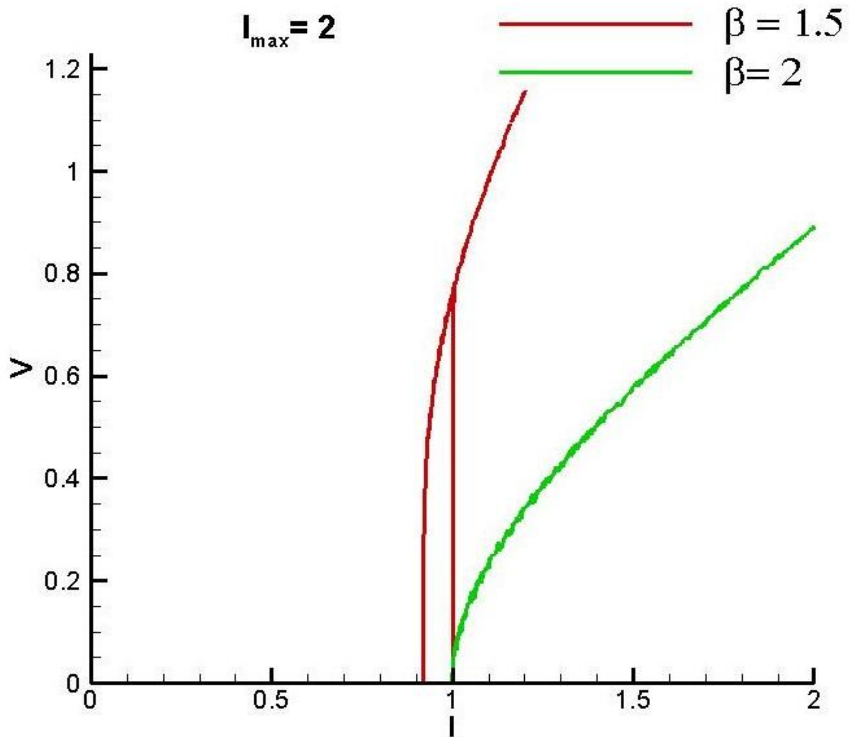
- Data of the simulation was generated and different plots were made to study the behavior of the system in different conditions:
  - Plasma wave was detected that shows charging within the superconducting layers

Results and Discussion

RCSJ (SHORT JJ)

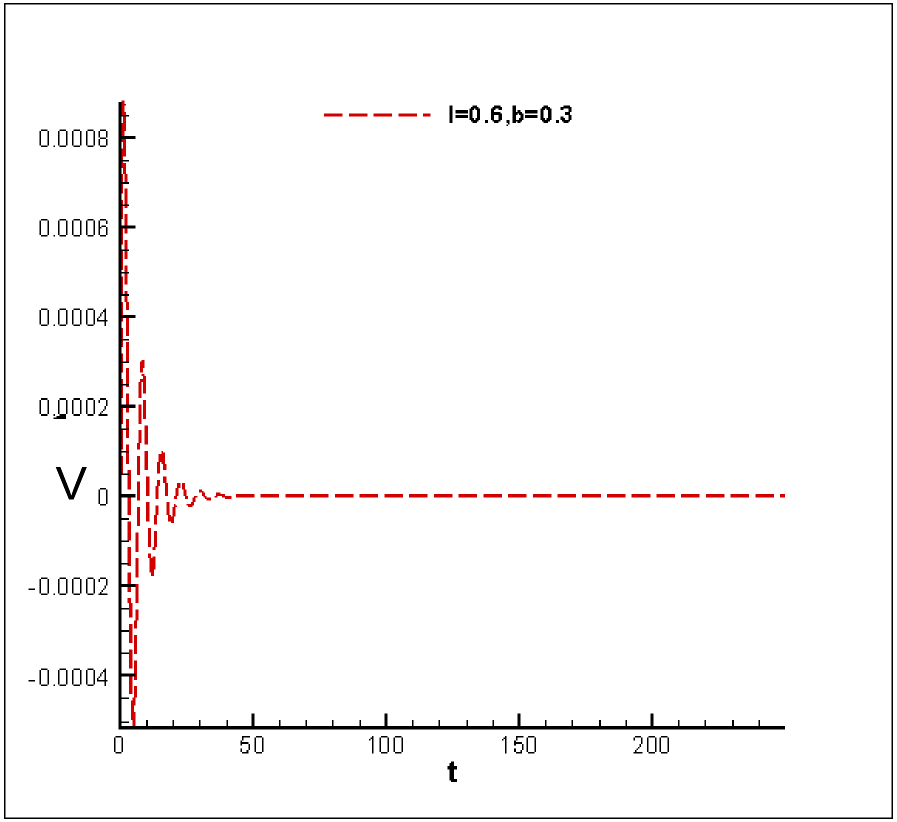


Underdamped: β<1



Overdamped: β>1

RCSJ (SHORT JJ)



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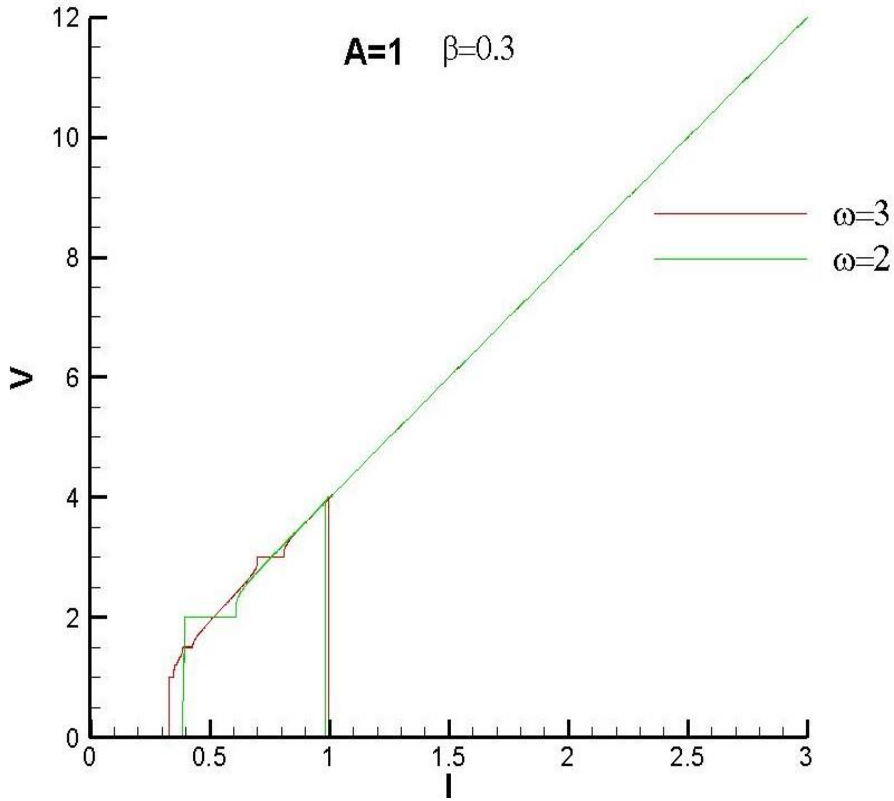
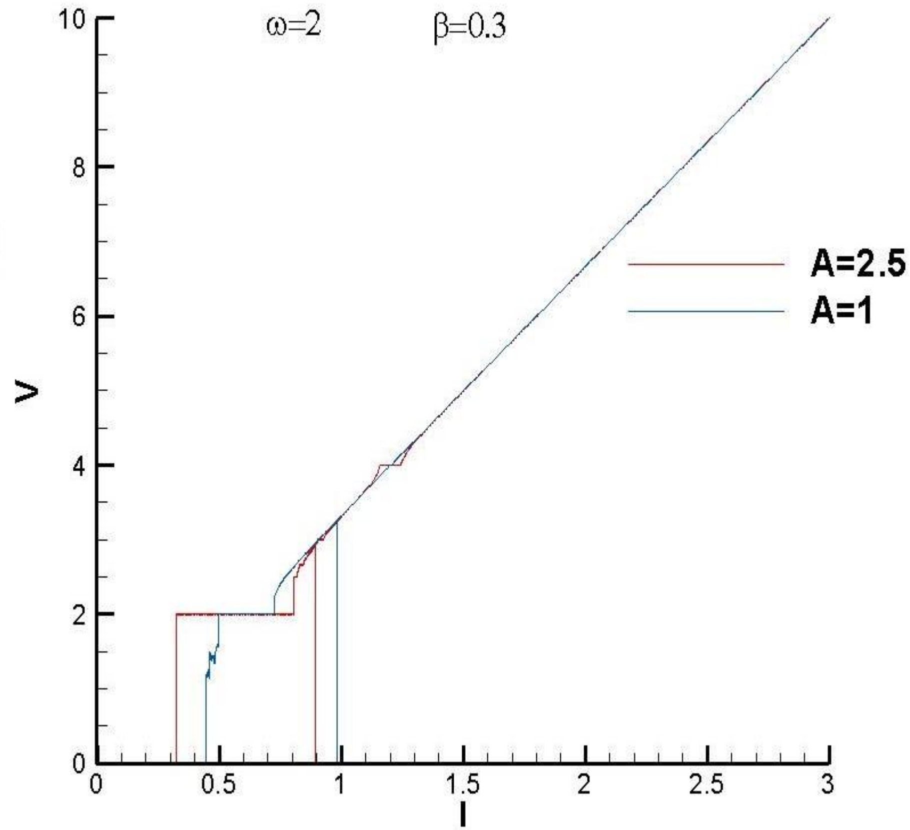
Effect of External Radiation

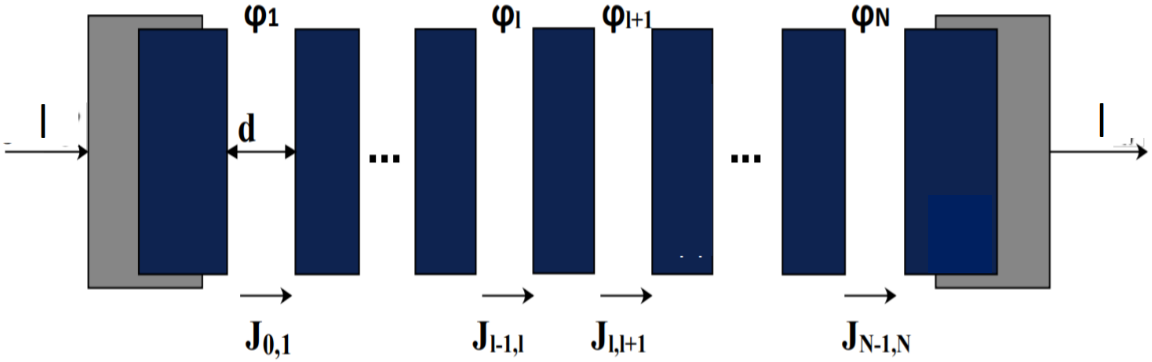




Shapiro steps

CCJJ+DC

Capacitive Coupled Josephson Junction with Diffusion Current



$$\frac{d\phi}{dt} = V \quad \Rightarrow \quad \frac{d\varphi_i}{dt} = V_i - \alpha(V_{i+1} + V_{i-1} - 2V_i) \qquad \alpha = \frac{\varepsilon\varepsilon_0}{2e^2 N(0) d}$$

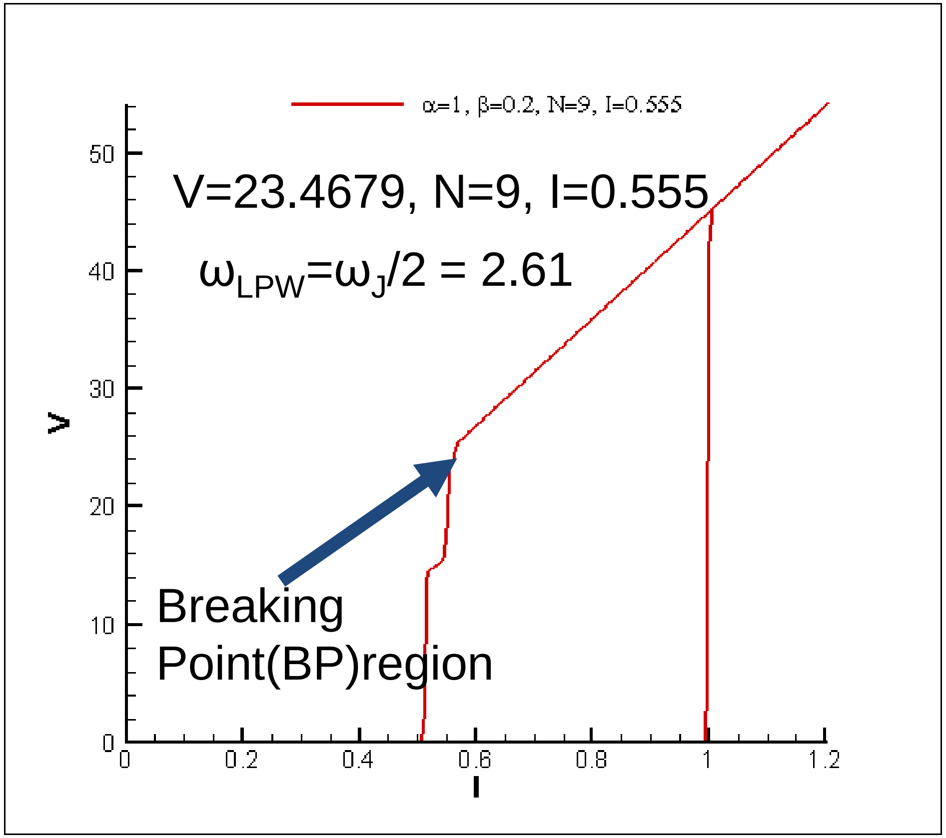
$$\frac{dV_i}{dt} = I - Sin\phi_i - \beta\frac{d\phi_i}{dt} \qquad \beta = \frac{1}{R}\sqrt{\frac{\eta}{2eI_C C}}$$

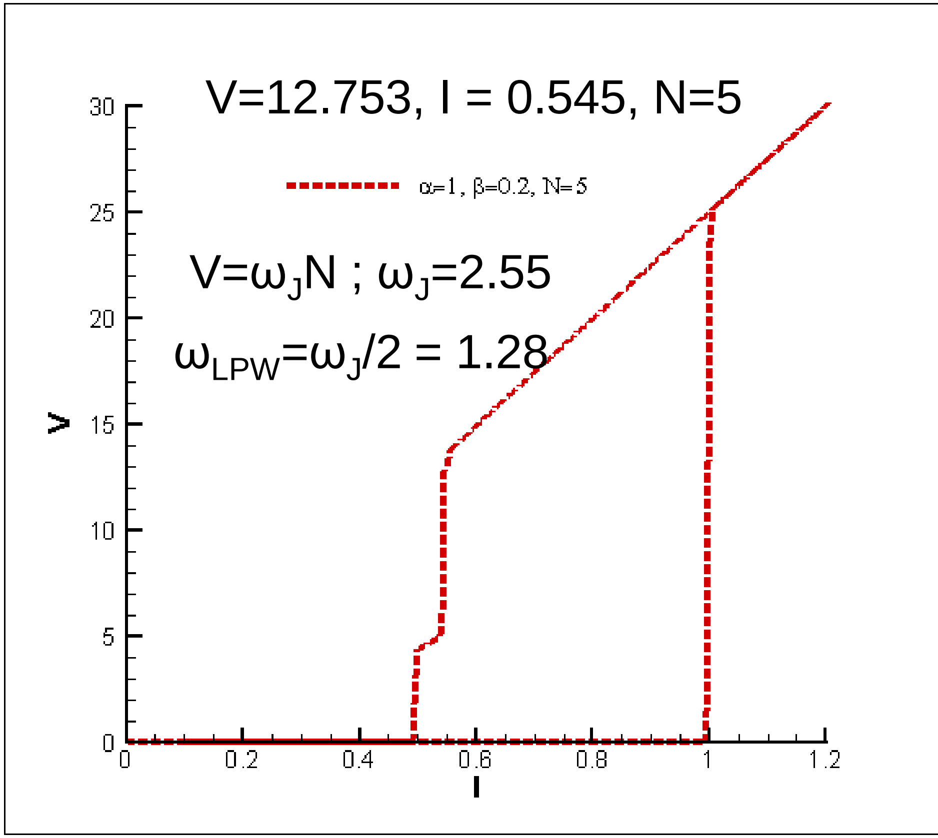
β = dissipation parameter

α= Coupling parameter

d= distance between the layers, N(0)=density of the states

CCJJ+DC





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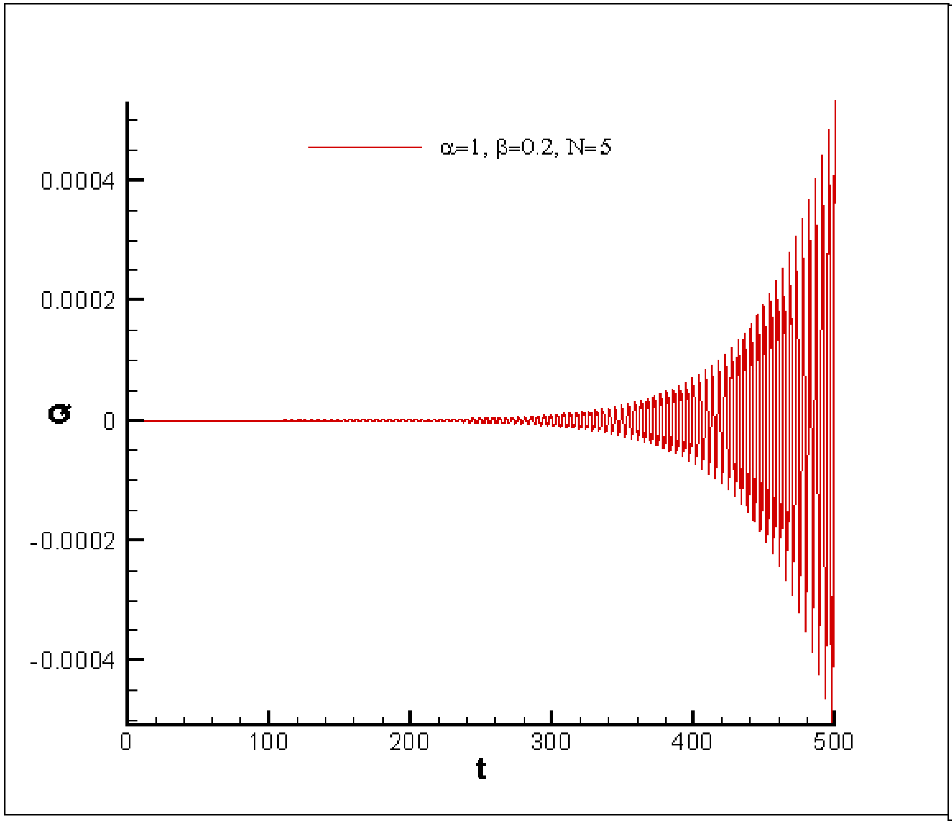
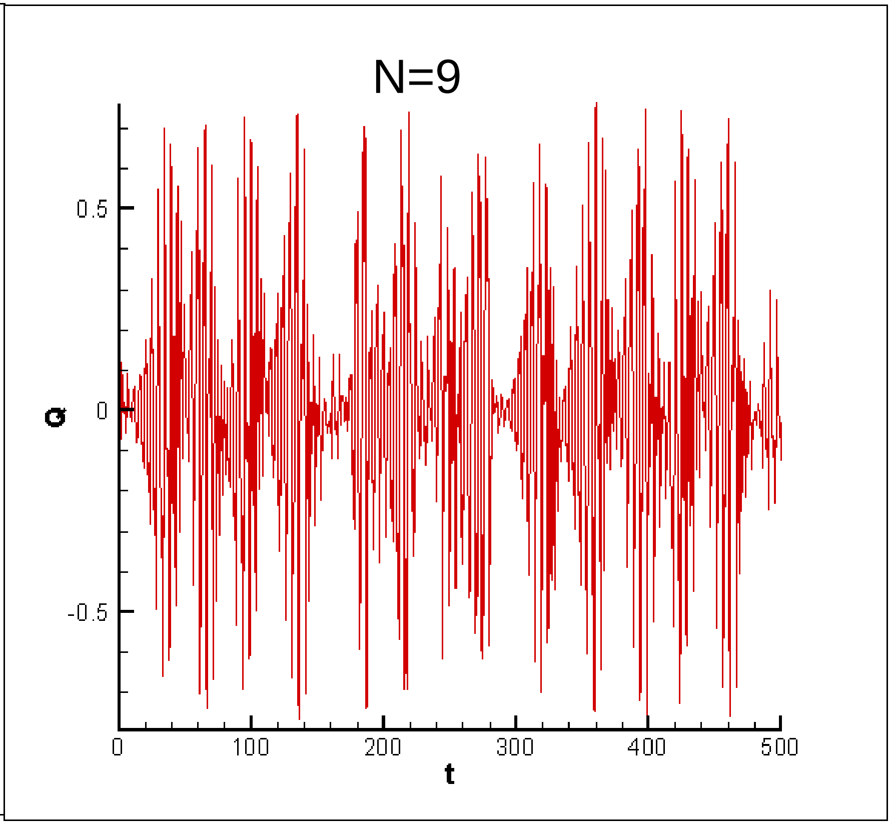
CCJJ+DC MODEL

Capacitive Coupled Josephson Junction with Diffusion Current





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JJ's importance in Superconducting Quantum Interference Devices

The SQUID may be configured as a magnetometer to detect incredibly small magnetic fields - small enough to measure the magnetic fields in living organisms.

Threshold for SQUID: 10^{-14} T
Magnetic field of heart: 10^{-10} T
Magnetic field of brain: 10^{-13} T

- *Many uses in everyday life*

•Scanning SQUID microscopy
(measurements of weak magnetic field)

• Geophysical applications of SQUID
(oil prospecting, earthquake prediction, geothermal energy surveying)

• Higher Temperature SQUIDs
(nondestructive testing of materials...)

Uses of SC magnets

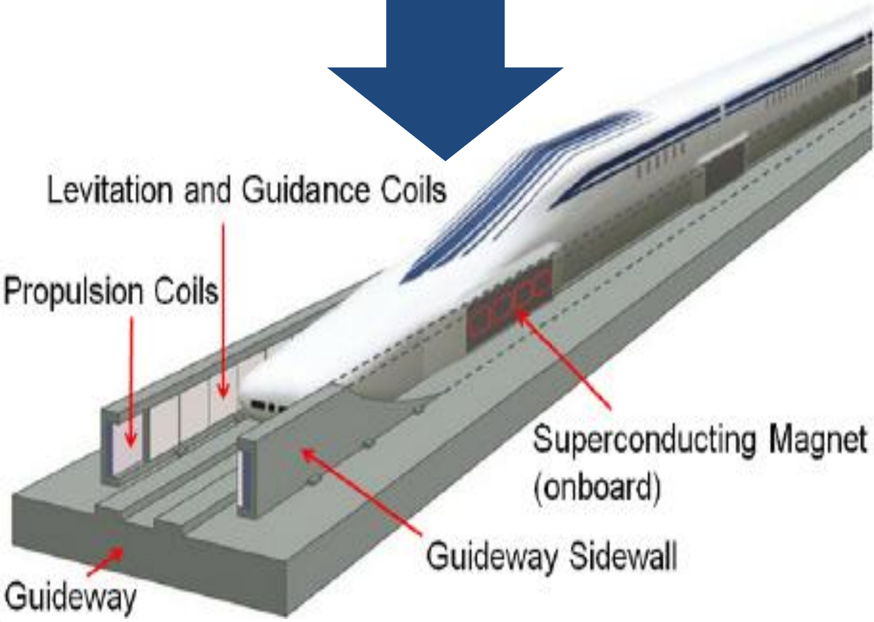
Applications of superconductivity

❖**Electrical applications**(Zero resistance, zero loss)

1. **power cables:**
   - smaller cables with more current.
   - cables have to be cooled to become superconducting. However, cable prototypes made of superconducting cuprates cooled with liquid nitrogen have been built on small distances.
2. **SMES (Energy storage):**
   - SMES = Superconducting Magnetic Energy Storage.

Power cable made of superconductors;

Maglev train



Can improve human relationship with electricity

Conclusion

- This study revealed certain specific effects in the coupled Josephson Junctions that weren’t so for single JJ.
- Propagation of longitudinal plasma waves in the breaking point region that causes charge time oscillation.

References

- Yu. M. Shukrinov and M.A Gaafar Phys. Rev. B 84, 094514(2011).
- W. Buckel and R. Kleiner, Superconductivity: fundamentals and applications. (Wisely-VCH, Verlag GmbH &Co. Kga A, 2004)

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Thank You